

Table of Contents

List of Figures	VIII
List of Tables	X
Executive Summary	XII
Acronyms, Abbreviations, and Units	XVI
Chapter 1. Introduction: Policy, Monitoring, and Synopsis of Air Quality	1-1
Air Quality Policy in National Parks and Monuments	1-3
Air Quality Monitoring in Class I National Parks and Monuments of the Colorado Plateau ..	1-6
IMPROVE Station Description and Rationale	1-8
Visibility Characterization	1-9
Overview of Conditions Across the Colorado Plateau	1-9
Sources	1-14
Case Studies of Visibility on the Colorado Plateau	1-15
Visibility Projections	1-15
Ozone.....	1-17
Ozone Sampling with Passive Samplers (1995 and 1996)	1-19
Sulfur Dioxide.....	1-21
Observed Concentrations of Sulfur Dioxide (1988 - 1994)	1-21
Nitrogen Oxides	1-22
Atmospheric Deposition	1-23
Other Oxidants, Toxics, Heavy Metals, Radioactive Nuclides	1-34
Aquatic Systems and AQRVs.....	1-34
References	1-35
Chapter 2. Sensitivities of Terrestrial and Aquatic Ecosystems to Air Pollutants	2-1
Ozone.....	2-1
Aspen	2-8
Douglas-fir.....	2-9
Ponderosa Pine.....	2-10
Shrubs.....	2-11
Grasses, Sedges, Forbs	2-13
Lichens.....	2-19
Sulfur Dioxide	2-20
Trees and Shrubs.....	2-20
Grasses and Forbs.....	2-25
Lichens and Microbiotic Crusts	2-25
Sensitivity of Aquatic Ecosystems.....	2-26
Acidification	2-26
Chronic Versus Episodic Acidification	2-28
Nitrogen Saturation	2-29
Eutrophication	2-30

Conclusions on Regional N and S Deposition	2-30
References	2-30
Chapter 3. Arches National Park	3-1
Introduction	3-1
Geology and Soils	3-1
Climate	3-3
Vegetation	3-5
Air Quality.....	3-6
Emissions.....	3-6
Air Pollutant Concentrations.....	3-7
Visibility	3-8
Aerosol Data	3-9
Photographs	3-12
Atmospheric Deposition	3-14
Sensitivity of Plants	3-14
Water Quality and Aquatic Organisms	3-15
Aquatic Invertebrates	3-15
Amphibians	3-16
Recommendations for Future Monitoring and Research.....	3-16
Park Summary.....	3-17
References	3-17
Chapter 4. Bandelier National Monument.....	4-1
Introduction	4-1
Geology and Soils	4-1
Climate	4-3
Vegetation	4-5
Air Quality.....	4-5
Emissions.....	4-6
Air Pollutant Concentrations.....	4-6
Visibility	4-7
Optical Data - Transmissometer.....	4-8
Aerosol Data	4-10
Photographs	4-13
Atmospheric Deposition	4-15
Sensitivity of Plants	4-15
Water Quality and Aquatic Organisms	4-16
Aquatic Invertebrates	4-19
Amphibians	4-19
Fish	4-20
Recommendations for Future Monitoring and Research.....	4-21
Monument Summary	4-22

References	4-22
Chapter 5. Black Canyon of the Gunnison National Monument.....	5-1
Introduction	5-1
Geology and Soils	5-1
Climate	5-3
Vegetation	5-3
Air Quality.....	5-4
Emissions.....	5-4
Air Pollutant Concentrations and Atmospheric Deposition.....	5-5
Visibility	5-5
Sensitivity of Plants	5-5
Water Quality.....	5-5
Recommendations for Future Research	5-7
Monument Summary	5-7
References	5-8
Chapter 6. Bryce Canyon National Park	6-1
Introduction	6-1
Geology and Soils	6-1
Climate	6-3
Vegetation	6-3
Air Quality.....	6-4
Emissions.....	6-4
Air Pollutant Concentrations.....	6-5
Visibility	6-6
Aerosol Data	6-7
Photographs	6-9
Visibility Projections.....	6-9
Atmospheric Deposition	6-13
Sensitivity of Plants	6-13
Water Quality and Aquatic Organisms	6-14
Aquatic Invertebrates	6-14
Amphibians	6-14
Water Quality Conclusions	6-14
Recommendations for Future Monitoring and Research.....	6-14
Park Summary.....	6-15
References	6-15
Chapter 7. Canyonlands National Park	7-1
Introduction	7-1
Geology and Soils	7-1
Climate	7-3
Vegetation	7-5

Air Quality.....	7-6
Emissions.....	7-6
Air Pollutant Concentrations.....	7-7
Visibility	7-8
Optical Data - Transmissometer.....	7-8
Aerosol Data	7-10
Photographs	7-13
Visibility Projections.....	7-15
Atmospheric Deposition	7-18
Sensitivity of Plants	7-18
Water Quality and Aquatic Organisms	7-19
Recommendations for Future Monitoring and Research.....	7-19
Park Summary.....	7-19
References.....	7-20
Chapter 8. Capitol Reef National Park	8-1
Introduction	8-1
Geology and Soils	8-1
Climate	8-3
Vegetation	8-3
Air Quality.....	8-5
Emissions.....	8-5
Air Pollutant Concentrations.....	8-6
Atmospheric Deposition	8-6
Sensitivity of Plants	8-7
Water Quality and Aquatic Organisms	8-8
Recommendations for Future Monitoring and Research.....	8-9
Park Summary.....	8-10
References.....	8-10
Chapter 9. Grand Canyon National Park.....	9-1
Introduction	9-1
Geology and Soils	9-1
Climate	9-2
Vegetation	9-6
Air Quality.....	9-8
Emissions.....	9-8
Air Pollutant Concentrations.....	9-10
Visibility	9-12
Optical Data - Transmissometer.....	9-13
Aerosol Data	9-15
Photographs	9-20
Visibility Projections.....	9-22

Atmospheric Deposition	9-24
Sensitivity of Plants	9-24
Water Quality and Aquatic Organisms	9-25
Amphibians	9-25
Fish	9-26
Recommendations for Future Monitoring and Research.....	9-26
Park Summary.....	9-27
References	9-27
Chapter 10. Great Sand Dunes National Monument	10-1
Introduction	10-1
Geology and Soils	10-1
Climate	10-3
Vegetation	10-5
Air Quality.....	10-5
Emissions.....	10-5
Air Pollutant Concentrations.....	10-6
Visibility	10-7
Aerosol Data	10-8
Photographs	10-11
Atmospheric Deposition	10-13
Sensitivity of Plants	10-13
Water Quality and Aquatic Organisms	10-14
Amphibians	10-14
Recommendations for Future Monitoring and Research.....	10-14
Park Summary.....	10-15
References	10-15
Chapter 11. Mesa Verde National Park	11-1
Introduction	11-1
Geology and Soils	11-1
Climate	11-3
Vegetation	11-6
Air Quality.....	11-6
Emissions.....	11-6
Air Pollutant Concentrations.....	11-7
Visibility	11-8
Optical Data - Transmissometer.....	11-9
Aerosol Data	11-11
Photographs	11-14
Visibility Projections.....	11-16
Atmospheric Deposition	11-19
Sensitivity of Plants	11-19

Water Quality and Aquatic Organisms	11-20
Amphibians	11-20
Recommendations for Future Monitoring and Research.....	11-20
Park Summary.....	11-21
References	11-21
Chapter 12. Petrified Forest National Park	12-1
Introduction	12-1
Geology and Soils	12-1
Climate	12-3
Vegetation	12-5
Air Quality.....	12-5
Emissions.....	12-5
Air Pollutant Concentrations.....	12-6
Visibility	12-7
Optical Data - Transmissometer.....	12-8
Aerosol Data	12-10
Photographs	12-13
Atmospheric Deposition and Water Quality.....	12-15
Sensitivity of Plants	12-15
Recommendations for Future Monitoring and Research.....	12-15
Park Summary.....	12-16
References	12-16
Chapter 13. Zion National Park.....	13-1
Introduction	13-1
Geology and Soils	13-1
Climate	13-3
Vegetation	13-4
Air Quality.....	13-4
Emissions.....	13-4
Air Pollutant Concentrations, Visibility, and Atmospheric Deposition.....	13-5
Sensitivity of Plants	13-5
Water Quality and Aquatic Organisms	13-6
Aquatic Invertebrates	13-6
Recommendations for Future Monitoring and Research.....	13-7
Park Summary.....	13-8
References	13-8
Chapter 14. Colorado Plateau Summary and Recommendations	14-1
Changes in the Colorado Plateau	14-1
Visibility	14-2
Air Pollutant Impacts on Vegetation	14-3
Sensitivity of Soils and Surface Water to Acidification	14-3

Recommendations	14-4
References	14-7

Appendix

Master List of References in the Report.....	A-1
Acknowledgments	A-13
People Contacted at Each Park or Monument.....	A-13
Other Scientists and Resource Managers Contacted	A-14

List of Figures

Figure 1-1. Class I National Parks and Monuments of the Colorado Plateau	1-2
Figure 1-2. Schematic structure of each chapter's structure	1-3
Figure 1-3. Six-year averages of total reconstructed light extinction coefficient for the U.S.	1-11
Figure 1-4. Visibility across the U.S.....	1-12
Figure 1-5. Precipitation pH for the Colorado Plateau	1-26
Figure 1-6. Rainfall pH for the U.S.....	1-27
Figure 1-7. Ammonium deposition for the Colorado Plateau	1-28
Figure 1-8. Ammonium deposition for the U.S.....	1-29
Figure 1-9. Nitrate deposition for the Colorado Plateau.....	1-30
Figure 1-10. Nitrate deposition for the U.S.	1-31
Figure 1-11. Sulfate deposition for the Colorado Plateau	1-32
Figure 1-12. Sulfate deposition for the U.S.	1-33
Figure 3-1. Location of Arches National Park.	3-2
Figure 3-2. Mean daily temperature and monthly precipitation for Arches National Park.....	3-3
Figure 3-3. Seasonal wind roses for Arches National Park	3-4
Figure 3-4. Reconstructed extinction budgets for Arches National Park.	3-11
Figure 3-5. Photographs representing visibility conditions at Arches National Park.....	3-13
Figure 4-1. Location of Bandelier National Monument.....	4-2
Figure 4-2. Seasonal wind roses for Bandelier National Monument (1990-1993)	4-4
Figure 4-3. Reconstructed extinction budgets for Bandelier National Monument	4-12
Figure 4-4. Photographs representing visibility conditions at Bandelier NM.....	4-14
Figure 4-5. Streams of Bandelier National Monument (with a burned area shaded).....	4-17
Figure 5-1. Location of Black Canyon of the Gunnison National Monument.	5-2
Figure 6-1. Location of Bryce Canyon National Park.....	6-2
Figure 6-2. Reconstructed extinction budgets for Bryce Canyon National Park.	6-8
Figure 6-3. Photographs representing visibility conditions at Bryce Canyon National Park.	6-10
Figure 6-4. Projected "baseline" light extinction for Bryce Canyon National Park	6-11
Figure 6-5. Projected "baseline" visibility for Bryce Canyon National Park.....	6-12
Figure 7-1. Location of Canyonlands National Park.	7-2

Figure 7-2.	Mean daily temperature and monthly precipitation for Canyonlands NP.....	7-3
Figure 7-3.	Wind rose for Canyonlands National Park.....	7-4
Figure 7-4.	Reconstructed extinction budgets for Canyonlands National Park.....	7-12
Figure 7-5.	Photographs representing visibility conditions at Canyonlands National Park.	7-14
Figure 7-6.	Projected “baseline” light extinction for Canyonlands National Park.	7-16
Figure 7-7.	Projected “baseline” visibility for Canyonlands National Park	7-17
Figure 8-1.	Location of Capitol Reef National Park.....	8-2
Figure 9-1.	Location of Grand Canyon National Park.	9-3
Figure 9-2.	Mean daily temperature and monthly precipitation for the South Rim.....	9-4
Figure 9-3.	Seasonal wind roses for Grand Canyon National Park.	9-5
Figure 9-4.	Reconstructed extinction budgets for Grand Canyon National Park.	9-17
Figure 9-5.	Reconstructed extinction budgets for Indian Gardens.....	9-19
Figure 9-6.	Photographs representing visibility conditions at Grand Canyon National Park	9-21
Figure 9-7.	Projected “baseline” light extinction for Grand Canyon National Park.....	9-23
Figure 9-8.	Projected “baseline” visibility for Grand Canyon National Park	9-23
Figure 10-1.	Location of Great Sand Dunes National Monument.	10-2
Figure 10-2.	Mean daily temperature and monthly precipitation for Great Sand Dunes NM. .	10-3
Figure 10-3.	Seasonal wind roses for Great Sand Dunes National Monument.	10-4
Figure 10-4.	Reconstructed extinction budgets for Great Sand Dunes National Monument	10-10
Figure 10-5.	Photographs representing visibility conditions at Great Sand Dunes NM.	10-12
Figure 11-1.	Location of Mesa Verde National Park.	11-2
Figure 11-2.	Mean daily temperature and monthly precipitation for Mesa Verde NP.	11-3
Figure 11-3.	Seasonal wind roses for Mesa Verde National Park.	11-5
Figure 11-4.	Reconstructed extinction budgets for Mesa Verde National Park.	11-13
Figure 11-5.	Photographs representing visibility conditions at Mesa Verde National Park...	11-15
Figure 11-6.	Projected “baseline” light extinction for Mesa Verde National Park.....	11-17
Figure 11-7.	Projected “baseline” visibility for Mesa Verde National Park	11-18
Figure 12-1.	Location of Petrified Forest National Park.	12-2
Figure 12-2.	Mean daily temperature and monthly precipitation for Petrified Forest NP.	12-3
Figure 12-3.	Seasonal wind roses for Petrified Forest National Park.	12-4
Figure 12-4.	Reconstructed extinction budgets for Petrified Forest National Park.	12-12
Figure 12-5.	Photographs representing visibility conditions at Petrified Forest NP.	12-14
Figure 13-1.	Location of Zion National Park.	13-2
Figure 13-2.	Mean daily temperature and monthly precipitation for Zion National Park	13-3
Figure 14-1.	Census Bureau population for counties of the Colorado Plateau.....	14-1
Figure 14-2.	Census Bureau population for the four-corner states.....	14-1
Figure 14-3.	Visitation, employment, and expenditure in the NPS areas.	14-2

List of Tables

Table 1-1.	National Ambient Air Quality Standards	1-5
Table 1-2.	Air quality monitoring in Class I National Parks and Monuments	1-7
Table 1-3.	Transmissometer visibility monitoring sites for geographic regions.....	1-13
Table 1-4.	Colorado Plateau extinction apportioned by general category	1-14
Table 1-5.	Contributions of various types of fine particles to light extinction	1-14
Table 1-6.	Ozone concentrations and exposures between May and September.	1-18
Table 1-7.	Average hourly ozone for weekly samples	1-20
Table 1-8.	Sulfur dioxide measured by IMPROVE filter samplers	1-22
Table 2-1.	Reported sensitivity of tree and shrub species to ozone.	2-5
Table 2-2.	Reported sensitivity of forbs, sedges, and grasses to ozone.	2-14
Table 2-3.	Reported sensitivity of vascular plants and lichens to sulfur dioxide	2-21
Table 3-1.	Emissions for counties surrounding Arches National Park.	3-7
Table 3-2.	Concentrations of ozone and sulfur dioxide for Arches National Park.....	3-8
Table 3-3.	Visual range and light extinction coefficients for Arches National Park.	3-9
Table 3-4.	Atmospheric deposition for Green River, Utah.	3-14
Table 4-1.	Emissions for counties surrounding Bandelier National Monument.	4-6
Table 4-2.	Concentrations of ozone and sulfur dioxide for Bandelier National Monument....	4-7
Table 4-3.	Transmissometer data summary for Bandelier National Monument.	4-9
Table 4-4.	Standard visual ranges for Bandelier National Monument.	4-10
Table 4-5.	Visual range and light extinction coefficients for Bandelier National Monument .	4-11
Table 4-6.	Atmospheric deposition for Bandelier National Monument.....	4-15
Table 4-7.	Water chemistry for streams in Bandelier National Monument.....	4-18
Table 4-8.	Scientific and common names of fish in Bandelier National Monument.	4-21
Table 5-1.	Emissions for counties surrounding Black Canyon National Monument.	5-4
Table 6-1.	Emissions for counties surrounding Bryce Canyon National Park.	6-5
Table 6-2.	Concentrations of sulfur dioxide for Bryce Canyon National Park	6-5
Table 6-3.	Visual range and light extinction coefficients for Bryce Canyon National Park.....	6-7
Table 6-4.	Atmospheric deposition for Bryce Canyon National Park	6-13
Table 7-1.	Distribution of major communities in Canyonlands National Park	7-5
Table 7-2.	Emissions for counties surrounding Canyonlands National Park	7-6
Table 7-3.	Concentrations of ozone and SO ₂ for Canyonlands National Park.....	7-7
Table 7-4.	Transmissometer data summary for Canyonlands National Park.	7-9
Table 7-5.	Standard visual range for Canyonlands National Park.	7-10
Table 7-6.	Visual range and light extinction coefficients for Canyonlands National Park.	7-11
Table 7-7.	Atmospheric deposition for Green River, Utah.	7-18
Table 8-1.	Emissions for counties surrounding Capitol Reef National Park	8-6
Table 8-2.	Atmospheric deposition for Green River, Utah	8-7
Table 8-3.	Water chemistry from tanks in Capitol Reef National Park.....	8-9
Table 9-1.	Vegetation communities of Grand Canyon National Park.	9-7

Table 9-2.	Emissions for counties surrounding Grand Canyon National Park.....	9-9
Table 9-3.	Micro-inventory of emissions in Grand Canyon National Park	9-10
Table 9-4.	Concentrations of ozone and SO ₂ for Grand Canyon National Park	9-12
Table 9-5.	Transmissometer data for the South Rim, Grand Canyon National Park.	9-14
Table 9-6.	Standard visual range for the South Rim, Grand Canyon National Park.....	9-15
Table 9-7.	Visual range and light extinction coefficients for Grand Canyon National Park...9-16	
Table 9-8.	Atmospheric deposition for Grand Canyon National Park.	9-24
Table 10-1.	Emissions for counties surrounding Great Sand Dunes National Monument.....	10-6
Table 10-2.	Concentrations of ozone and sulfur dioxide for Great Sand Dunes NM.	10-7
Table 10-3.	Visual range and light extinction coefficients for Great Sand Dunes NM	10-8
Table 10-4.	Atmospheric deposition for Alamosa, CO, near Great Sand Dunes NM.	10-13
Table 11-1.	Emissions for counties surrounding Mesa Verde National Park.	11-7
Table 11-2.	Concentrations of ozone and SO ₂ for Mesa Verde National Park.	11-8
Table 11-3.	Transmissometer data summary for Mesa Verde National Park.	11-10
Table 11-4.	Standard visual range for Mesa Verde National Park.....	11-11
Table 11-5.	Visual range and light extinction coefficients for Mesa Verde National Park....	11-12
Table 11-7.	Atmospheric deposition for Mesa Verde National Park.	11-19
Table 12-1.	Emissions for counties surrounding Petrified Forest National Park.	12-6
Table 12-2.	Concentrations of ozone and SO ₂ for Petrified Forest National Park.	12-7
Table 12-3.	Transmissometer data summary for Petrified Forest National Park.	12-9
Table 12-4.	Standard visual range for Petrified Forest National Park.....	12-10
Table 12-5.	Visual range and light extinction coefficients for Petrified Forest NP.	12-11
Table 13-1.	Emissions for counties surrounding Zion National Park.	13-5